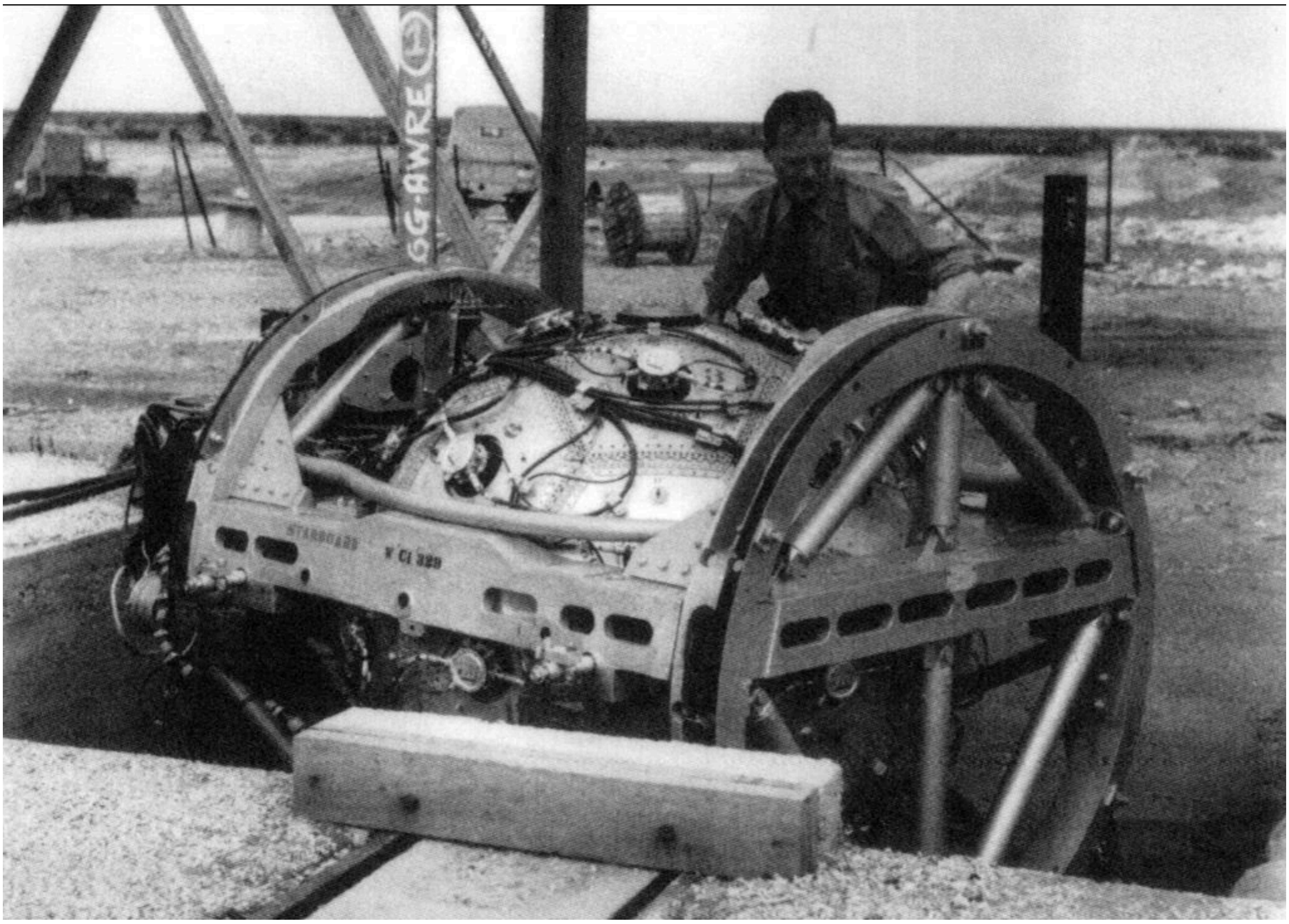
Cuba against any Western city would result in a FULL RETALITORY STRIKE ON RUSSIA. There was no risk of nuclear war then except by accident, and Kennedy had in his 25 May 1961 speech on "Urgent National Needs" a year and a half before instigated NUCLEAR SHELTERS in public basement buildings to help people in cities survive (modern concrete buildings survive near ground zero Hiroshima, as proved by declassified USSBS reports kept covered up by Uncle Sam). NOE THAT THERE IS A CREDIBLE THREAT OF NUCLEAR TESTS AND HIROSHIMA TYPE INTIMIDATION STRIKES, THE BBC FINALLY DECIDES TO SUPPRESS NUCLEAR NEWS SUPPOSEDLY TO HELP "ANTI-NUCLEAR" RUSSIAN PROPAGANDA TRYING TO PREVENT US FROM GETTING CREDIBLE DETERRENCE OF INVASIONS, AS WE HAD WITH THE W79 UNTIL DISARMERS REMOVED IT IN THE 90s! This stinks of prejudice, the usual sort of hypocrisy from the 1930s "disarmament heroes" who lied their way to Nobel peace prizes by starting a world war!

The facts from Hiroshima and Nagasaki for the shielding of blast and radiation effects by modern concrete buildings in the credible nuclear deterrence of invasions (click here for data) which - unlike the countervalue drivel that failed to prevent WW2 costing millions of human lives - worked in the Cold War despite the Western media's obsession with treating as Gospel truth the lying anti-nuclear propaganda from Russia's World Peace Council and its allies (intended to make the West disarm to allow Russian invasions without overwhelming, effective deterrence or opposition, as worked in Ukraine recently)!

Realistic effects and credible nuclear weapon capabilities are required now for deterring or stopping aggressive invasions and attacks which could escalate into major conventional or nuclear wars. Credible deterrence necessitates simple, effective protection against concentrated and dispersed invasions and bombing. The facts can debunk massively inaccurate, deliberately misleading CND "disarm or be annihilated" pro-dictatorship ("communism" scam) political anti-nuclear deterrence dogma. Hiroshima and Nagasaki anti-nuclear propaganda effects lies on blast and radiation for modern concrete cities is debunked by solid factual evidence kept from public sight for political reasons by the Marx-media, which is not opposed by the fashion-obsessed remainder of the media, and so myths sneak into "established pseudo-wisdom" by the back-door.

Sunday, August 02, 2009

Glasstone and Dolan nuclear crater sizes exaggeration



ABOVE: The 1956 Australian-British Maralinga cratering nuclear surface burst, Buffalo-2, prepared for firing at Marcoo site. The middle

of the weapon is carefully aligned to the height of the ground surface. Notice however that the weapon, despite having a low yield of just 1.4 kt, is a massive implosion device with a diameter of 5 feet. The heavy weight of the implosion system and carrying cradle *added mass for the "case shock" of the weapon increasing the energy carried by that dense case shock,* as opposed to the percentage of energy released from the weapon as the X-ray emission; the altered partition of energy between bomb case kinetic energy and X-ray fireball energy dramatically increase the cratering and ground shock effects.

X-rays dispersed outside of the bomb have only a trivial effect on the ground, ablating a thin surface layer of the ground and heating up the air, contributing mostly to air blast, not direct ground shock or cratering (it does produce the "air slap" ground shock, but this is rapidly dissipated with depth into the ground). *The downward portion of the dense case shock, on the other hand, embeds itself deeply into the ground, and is the major source of cratering and direct ground shock, coupling about half of the case shock kinetic energy into the surface and producing essentially all of the cratering and close-in ground shock energy.*

Air-slap from the blast produces on a trivial effect on the crater and ground shock because of its relatively low density (the transfer of energy from an air shock wave into the ground is trivial because of the mismatch of acoustic impedance in the two media, due to the fact that the ground is much denser than the air shock wave even at the greatest overpressures near ground zero). Heavy weapons with a relatively small yield to mass ratio are thus *far* more effective at cratering than modern lightweight designs. (This bomb design effect on cratering was proved by H. L. Brode and R. L. Bjork in their 1960 RAND Corporation report RM-2600, *Cratering from a Megaton Surface Burst,* but was never even mentioned in Glasstone's *Effects of Nuclear Weapons.*)

FIGURE 9-16b. HARDTACK, SHOT KOA, ENIWETOK ATOLL, SITE GENE, 13 MAY 1958, 1.37 MT, PHOTO: D + 8, 21 MAY 1958, POST-SHOT CONCRETE BEAM EXP, 6.5 FT. LOWER THAN PRE-SHOT AT 1,830 FT., PO = 1,130 PSI, RA = 2,160 FT.

9-33

Above: excerpt from Dr Frank H. Shelton's revised (2nd printing, 1990) book *Reflections of a nuclear weaponeer*, dealing with cratering (earlier in the book he gives an account of his Wednesday 25 March 1987 slide show on "Thermonuclear weapon tests and Pacific craters", debunking Glasstone and Dolan's *Effects of Nuclear Weapons* analysis at Lawrence Livermore National Laboratory, and the next day, at 10am in Edward Teller's office at that lab, he explained how American nuclear test cratering analysis was fatally flawed, receiving in return Teller's usual complete incomprehension, disinterest and lack of support for nuclear weapons effects improvements. Shelton had visited a concrete beam experiment at Eniwetok Atoll (color photos above from page 9-33 of Shelton's book): after the 1.37 megaton Koa surface burst, they were sticking up above the ground surface. This proved that the Pacific coral craters are not the ejecta cratering that occurs in dry soil, but merely compression of coral by high pressure. Teller didn't want to know. This problem continues in the whole DTRA approach to the revision of cratering, e.g. failing to publish an unclassified correction/update for the 1977 Glasstone and Dolan *Effects of Nuclear Weapons*, and bungling the cratering chapter 3 of the 1992 revised EM-1 as abstracted in John A. Northrop's 1996 limited-distribution *Handbook of Nuclear Weapon Effects: Calculational Tools Abstracted from EM-1*. The latter masters the art of being as clear as mud, by obfuscating the crater dimensions corrections, by breaking the crater scaling laws into two parts: section 3.1.1.2 on page 79 and table 3.3 on page 84 assume that the initial x-ray yield fraction varies from <20% at <1 kt to >80% at >20 kt, and gives scaling laws based on these assumptions for various soil types, which appear to contradict what Northrop writes on page 80, section 3.1.1.4 where he writes that for "small yield" weapons the crater volumes are directly proportional to yield (*so for conventional bombs and sub-kiloton nuclear weapons, the crater diameter and depth scale as the cube-root of yield*), whereas for "**higher yields, where gravity effects become important**", crater sizes scale less than proportionally with yield! (But after that very brief useful mention, Northrop says nothing further of the effect of gravity on the huge recent crater scaling law revisions!)

However, Northrop on page 86, section 3.1.3, suddenly discloses how EM-1 incorporates gravity effects at high yields (without mentioning "gravity" at that point): he states that the crater scaling laws in the earlier sections of the chapter are non-observable (pretty much imaginary) "dynamic crater size", and the observable or "apparent" crater is *smaller* due to a large proportion of the ejected material falling or slumping back into the crater, to partially re-fill it, which reduces the apparent crater size (the fallback effect)! Therefore, we find that the crater scaling laws he gave in table 3.3 are fictitious and need to be modified by a further equation (equation 3.16), which has a yield dependence that effectively changes the crater sizes scaling laws.

Northrop's equation 3.16 states that the apparent crater volume, $V_{\text{apparent}} = V_{\text{dynamic}}(1 - f_{\text{fallback}})$, where f_{fallback} is defined in equation 3.17 as $f_{\text{fallback}} = 0.27$ for all yields and soils apart from dry soil. *This constant value appears in serious error, contradicting other crater revisions data that we will discuss later in this blog post.* However, for dry soil and for high x-ray output weapons (yields of 20kt and above, with x-ray yields of 80% or greater), equation 3.18 yields: $f_{\text{fallback}} = 0.470 - 0.313W^{-0.145}$, where weapon W is yield in kilotons. This implies that $f_{\text{fallback}} = 0.157$ for 1kt, 0.355 for 1 Mt and 0.388 for 10 Mt. Thus, putting equation 3.18 into equation 3.17, we get $V_{\text{apparent}} = V_{\text{dynamic}}(0.530 + 0.313W^{-0.145}) = 0.843$ for 1 kt, 0.645 for 1 Mt and 0.612 for 10 Mt. These values do not give the correct crater scaling as compared to detailed results in articles and books on the revision to cratering, given later in this blog post. Northrop gives no graphs to evaluate or compare these formulae with nuclear test data, or with detailed computer cratering simulations. Consequently, Northrop's book is of no use in helping to understand or predict crater size revisions due to gravity effects.

Northrop in several places admits to confronting classification difficulties with secrecy on nuclear weapons effects, e.g. he only summarises 1993 EM-1 chapters 2-11, 14-16, 18 and 21-22, stating in his preface (p. iii) that the other 6 chapters of EM-1 are omitted from the handbook partly, "as a result of their extensive classified database". The thermal radiation and initial nuclear radiation data omit shielding due to city skylines are so are entirely misleading unless bombs are dropped on unobstructed deserts. This classification problem also affects his data summaries. E.g., Chapter 10, *Electromagnetic Pulse Effects,* omits the actual high altitude EM-1 EMP data (except for surface burst, where a detailed model for radiated surface burst EMP waveforms is provided), due to its secrecy classification and instead gives a simplified EMP model from report DNA-TR-84-47 (dated 1984) in figures 10.4 and 10.5, showing that a 400 km altitude burst produces a maximu peak EMP of 4, 20 and 40 kV/m for weapon prompt gamma ray yields of 0.1, 1 and 10 kt, respectively, while the fraction of this maximum which extends to the earth's horizon or tangent point ranges from 0.1-0.5 as prompt gamma ray yield is increased from 0.1-10 kt. While Northrop's book does contain many useful nuggets of data from the 1993 EM-1,including useful tables of neutron and gamma ray outputs from neutron bombs in tables 8.5 and 8.6 on page 337, and many useful graphs and tables of x-ray ablation effects for ABM or thermonuclear warhead design, it has many limitations on consistency. (Northrop's 1996 book is the result of thousands of pages of "sanitized" i.e. partly declassified EM-1 chapters, with deletions of data that can not be declassified, produced during the mid-1990s, as a result of a Freedom of Information Act request by a third-party, allegedly interested in arms control, which has failed to publish the information in full.)

Bruce G. Blair in his 1993 Brookings Institution book, *The Logic of Accidental Nuclear War,* pages 133-140 analyses the massive exaggerations by Glasstone and Dolan on crater/ground shock effects to buried shelters:

CHAPTER 4

Although the GEORGE detonation occurred 200 feet above the surface of the coral island, a shallow crater formed that was 10 feet deep and 1,140 feet in diameter, into which rolled the waters of Eniwetok lagoon a few minutes after the shot. The edge of the shallow depression, caused by pressure collapse of voids in the coral reef, was at about 5,000 pounds per inch (psi) blast pressure. If we had carefully noted this mechanism for crater formation in the coral reef material, the confusion regarding the crater dimension of large yield surface bursts in the Pacific as compared to extrapolations of small yield surface bursts in Nevada would have been resolved in the early 1950s instead of the early 1980s. The continuing classification of the yield of GEORGE event has contributed to a lack of appreciation of some of its nuclear weapon effects implications. (26)

The fact that JANGLE SURFACE burst not on the surface (the center of the device 3.5 feet above the ground) complicated understanding and calculations of the ir coupling of the bomb energy to the gro JANGLE UNCLE (17 feet underground) contained in an air-filled cubical plywood box the vertical hole was backfilled with sandb

JANGLE SURFACE burst was the first only surface burst of a nuclear device at Nevada Test Site. As a guest at the British r lear tests in Australia on Operation BUFFALO April 1956, I was escorted by Sir William Per on a tour of the site of their surface burst. A observing the configuration of the nuclear dev I remarked, "with the bomb half in and half ou the ground, you will have initial conditions that missed on JANGLE SURFACE burst." Altho the two yields were about the same, their cr dimensions were quite different, due to a c

CHAPTER 5

Which Is Best--A Surface Burst, Or A Smaller Yield Earth Penetrator?

A gun assembly type nuclear weapon had been developed that had, among other applications, the capability of ground penetration. The depth of penetration of the gun weapon depended upon the type of earth in the target area. A penetration of 30-40 feet was expected in sand, 45-60 feet in loam, and 85-100 feet in plastic clay.

Another possible nuclear weapon for cratering would be a surface burst bomb with a theoretical yield of about 83 KT. However, an implosion type bomb would not be capable of earth penetration, but could be a surface burst with a contact fuze.

If the hypothetical earth penetrator bomb was dropped in the center of an airfield runway, and penetrated to about 50 feet in depth, it would produce a crater 700 feet in diameter and 140 feet deep with a volume of 900,000 cubic yards. It would require about 30 days' work to fill in the bomb crater, working under deadly radioactive dose rates. The surface burst bomb would produce a crater 300 feet in diameter by 70 feet deep, with a volume of 68,000 cubic yards, that could be filled in in about a week, under similar radioactive environments as the underground burst. Clearly from a yield point of view, the smaller yield penetrating bomb was better than the surface burst weapon. However, an implosion bomb is less expensive than a gun type in fissile material equivalence. (9: JANGLE S&U fallout.)

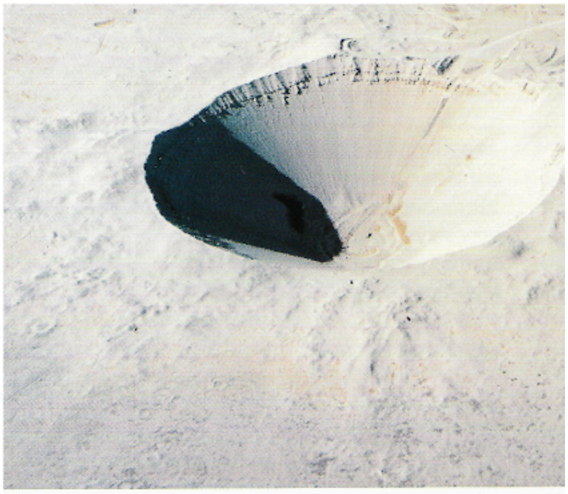


FIGURE 12-2. SEDAN CRATER, 6 JULY 1962, "CLEAN" 100 KT SAME SIZE CRATER AS 1 MT SURFACE BURST

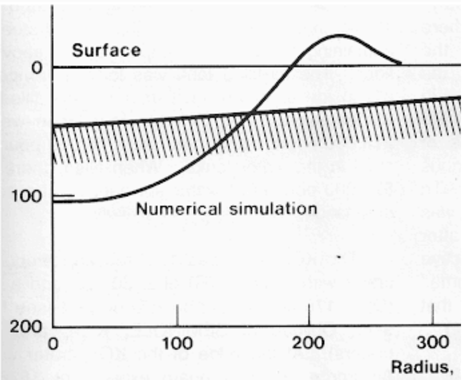
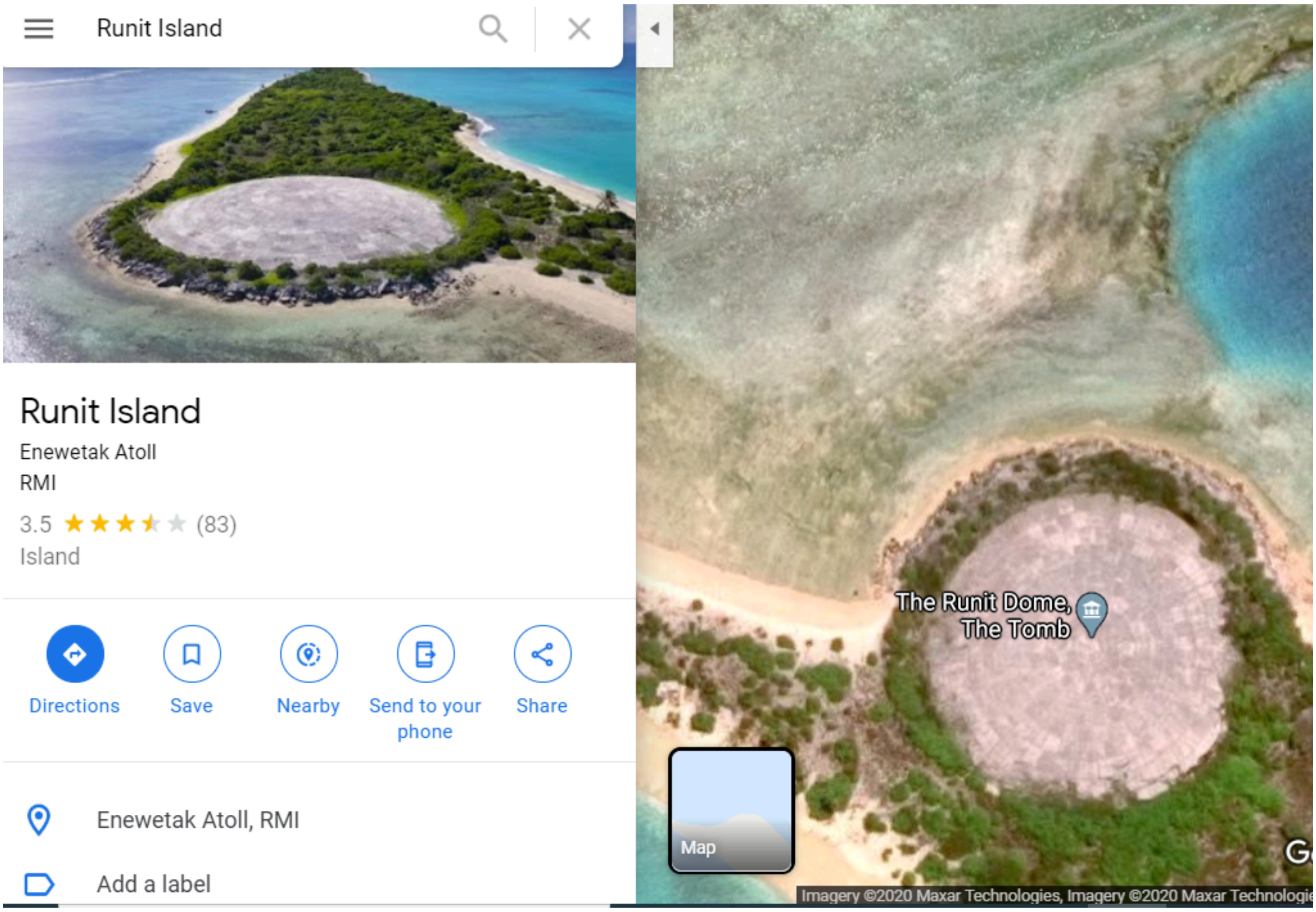


FIGURE 9-11b PACIFIC CRATER CALCULATIONS, PROI PRODUCED BY THE KOA EVENT, CONT TYPICAL NUMERICAL SIMULATION

FIGURE 9-16b. HARDTACK, SHOT POST-SHOT CONC

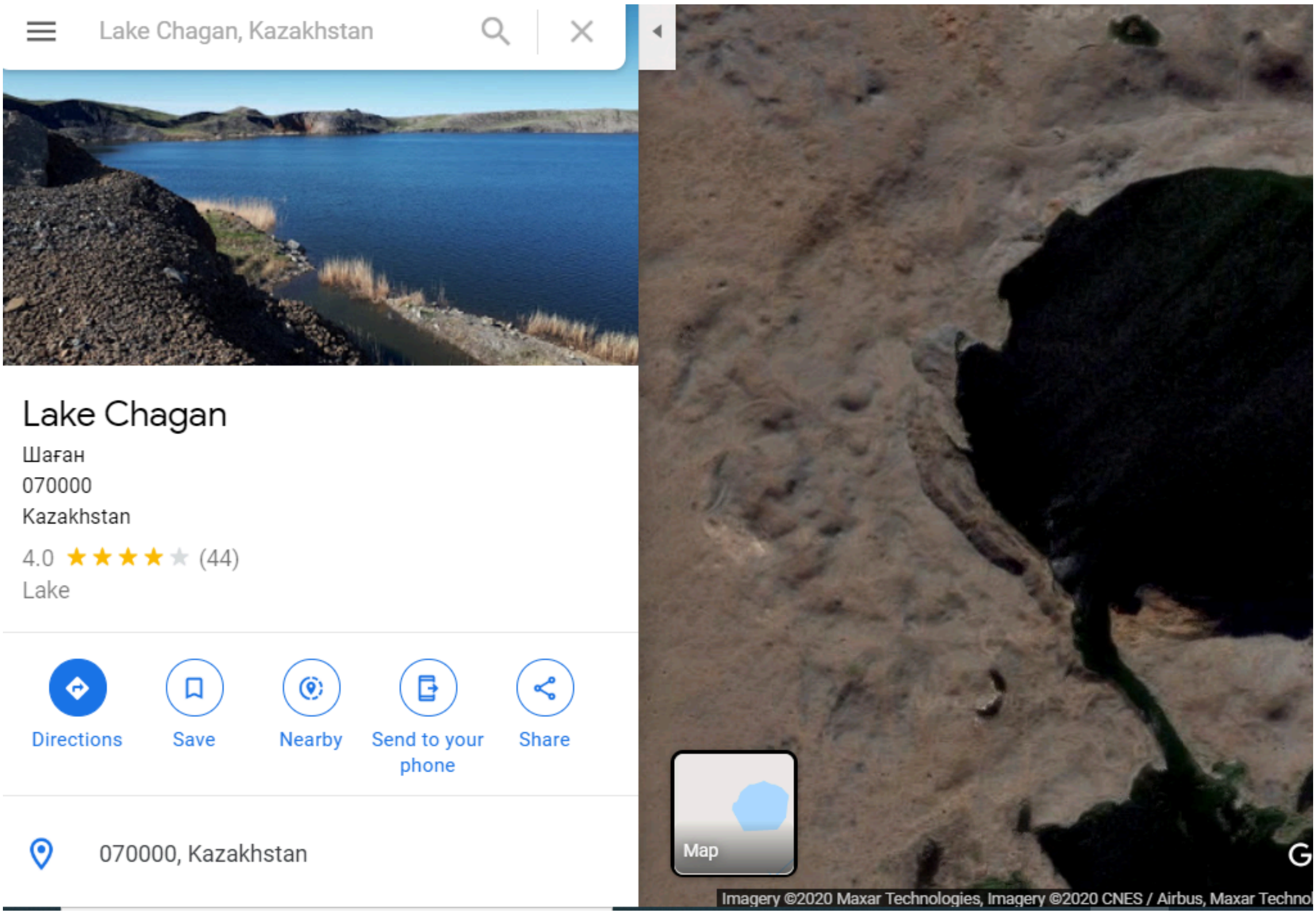
"... the most heavily fortified allegedly could withstand blast overpressures as high as several thousand pounds per square inch. ... a very deep command centre beneath the Kremlin ... in the early 1980s earned a Lenin Prize for former general secretary Chernenko. The largest underground complex ... was situated at Ramenki at an estimated depth of 650-1,000 feet. It could accommodate 10,000 people. ... Recently the U.S. Department of Defense reviewed the pertinent historical evidence gathered during nuclear tests and developed new models of the vulnerability of underground structures to nuclear explosions. These calculations differed substantially from those derived from earlier models. ... the dimensions of a crater produced by a nuclear explosion were estimated to be considerably smaller than previously thought. ... the radius of a crater produced by a 1 Mt nuclear explosion on the surface of wet soil [*crater radii will be only 58.3% this size in Moscow's wet soft rock, which is tougher to crater than wet soil*] would be 651 feet according to the old formula, whereas the new formula estimated the radius to be 394 feet. ... A 9 Mt bomb would have produced a crater radius of 590 feet in wet soil [*according to the new formula*] ... Under the new formula the pertinent calculations for this location's [*the shelter at Kuybishev where Stalin retreated in WWII*] geological composition (dry soft rock, according to U.S. analysts) indicate a crater radius of only 180 feet for a 1 Mt weapon, or 262 feet for a 9 Mt weapon. ... on the old formula ... crater radius would have been 485 and 937 feet for 1 Mt and 9 Mt..."



ABOVE: Google satellite photograph of Runit Island in Eniwetok Atoll, showing two nuclear weapon test craters. The 105 m diameter, 11 m deep crater from the 18 kt *Hardtack-Cactus* 6 May 1958 surface burst nuclear test crater on Runit Island was **used as a convenient nuclear waste dump during the decontamination of the Atoll in 1979, and was topped with a concrete dome**, which is visible in the Google satellite photograph. The 120 m diameter, 17 m deep water-filled crater in the reef seen in the photo above, just to the North-East of Runit Island, was formed by the 40 kt *Redwing-Lacrosse* nuclear test 17 feet over the reef on 5 May 1956.

The 15 megaton ***Castle-Bravo* test of 1 March 1954 and a later smaller test produced the two large overlapping craters shown below in the reef near Namu Island to the North-West of Bikini Atoll**:


Image © 2007 DigitalGlobe
©2006 Google™

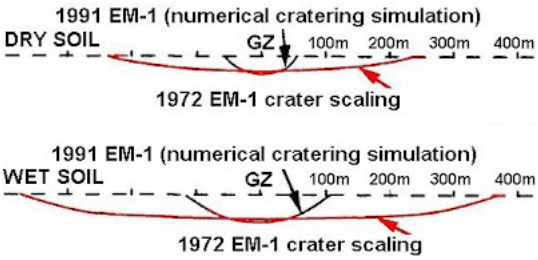

Lake Chagan, Kazakhstan
Lake Chagan
Шаған
070000
Kazakhstan
4.0 (44)
Lake
Directions
Save
Nearby
Send to your phone
Share
070000, Kazakhstan
Map
Imagery ©2020 Maxar Technologies, Imagery ©2020 CNES / Airbus, Maxar Technol

Above: the world's first nuclear explosion-created freshwater lake, *Lake Chagan*. It was produced on 15 January 1965 at the edge of the Semipalatinsk Test Site in Kazakhstan using a 140 kt (96% fusion, 4% fission) thermonuclear weapon, detonated 178 m underground in saturated siltstone (12% water), employing a two 3 kt fission primary stages. About 80% of the radioactivity was trapped underground and only 20% escaped into the atmosphere. The crater is 408 m in diameter and 100 m deep. The dose rate on the crater lip at 30 years after detonation was reported as 2.6 mR/hr, i.e. about 260 times the Earth's average natural background radiation level of 0.010 mR/hr, with the lake water in the crater containing just 300 pCi/litre. On the 10 October 1965, they detonated a 1.1 kt nuclear bomb at 48 m depth in weak siltstone rock under the dry clay bed of the Sary-Uzen stream. The crater produced was initially 107 m in diameter and 31 m deep, but when flooded it slumped to 20 m depth and 124 m diameter. Some 96.5% of the fission products were trapped underground, and the crater lip had a dose rate of only about 2.5 R/hr at 5 days after detonation, decaying to 0.050 mR/hr (including natural background) at 30 years later. (Data source: Milo D. Nordyke, *The Soviet Program for Peaceful Uses of Nuclear Explosions,* Lawrence Livermore National Lab., UCRL-ID-124410, July 1996, pp. 13-15.)

Crater radius for a surface burst on dry soil

1 Mt	10 Mt	U.S. Department of Defense source
192 m	414 m	*The Effects of Nuclear Weapons*, 1957, 1962, 1964
148 m	295 m	*The Effects of Nuclear Weapons*, 1977
58 m	92 m	*Capabilities of Nuclear Weapons*, 1991

1 MEGATON CONTACT SURFACE BURST CRATER



	DRY SOIL	WET SOIL
1972 EM-1	1,400 m^3/kt	5,700 m^3/kt
1991 EM-1	165 m^3/kt	775 m^3/kt

There are three reports now available online which throw light on the replacement to the **Glasstone and Dolan *Effects of Nuclear Weapons* and its secret supplement *Capabilities of Nuclear Weapons,* Effects Manual EM-1**:

1. **Kenneth E. Gould, *A Guide to Nuclear Weapons Phenomena and Effects Literature,* Kaman Tempo, Santa Barbara, CA., Technical Report ADB094426, DASIAC Special Report DASIAC-SR-206, 31 October 1984** which usefully states on **page 5**:

'*Capabilities of Nuclear Weapons,* DNA EM-1 (Reference C-2), is the best single comprehensive reference on all aspects of nuclear weapon phenomena and effects. This classified two-volume set both complements and supplements *The Effects of Nuclear Weapons.* Volume 1 focuses on nuclear weapon phenomenology and Volume 2 covers nuclear weapon effects that are primarily of military interest. This major DNA handbook, often referred to by its report number "EM-1," was last published in 1972 (with minor revisions through 1981), but it is presently being completely revised. When updated, EM-1 will again serve its important role as a basic source document for the preparation of nuclear operational and employment manuals by the military services.'

2. **John R. Murphy, et al., *Nuclear Effects Data Management and Analysis System (NEDMAS),* DSWA-TR-96-94, Defense Special Weapons Agency, 1997,** which gives some details of the new computer database for the effects of tests, and

3. **Ernest Bauer, *Variabilities in the Natural and Nuclear Endoatmospheric Environment,* Institute for Defense Analyses, Virginia, IDA Document D-1085, April 1992.**

Appendix A of this third report consists of a document by A. A. Fredrickson called *Revision of DNA Nuclear Crater Specifications,* taken from the September 1991 issue of *Nuclear Survivability*:

> DNA [Defense Nuclear Agency, which has since evolved into the **DTRA**] has recently completed an "end-to-end" cratering validation program that resulted in dramatic reduction of the crater size thought to result from the surface detonation of modem strategic weapons. Although a major field exploration and several underground nuclear tests conducted in this program occupied the spotlight, numerical simulations were in many ways more central to DNA's success. This article recounts the integrated role of the numerical simulations, re-interpretation of existing nuclear data, and additional field events in the evolution of DNA's view on nuclear cratering.
>
> DNA developed a crater specification methodology for its 1972 ***Capabilities of Nuclear Weapons - Effects Manual Number 1 (EM-1)*** with the acknowledgment that the nuclear database was incomplete and probably inappropriate for application to strategic yield surface burst weapons. The cratering events conducted at the Nevada Test Site (NTS) employed low yield sources suspected to produce larger craters than modern weapons of strategic interest. Data from the several high yield cratering events conducted at the Pacific Proving Grounds (PPG) were considered flawed by the atoll reef geology that was highly dissimilar to sites of interest. The 1972 **EM-1** methodology was an attempt to reconcile these shortcomings.

The strategic source surface burst crater specifications were based on high yield PPG data, calibrated to sites of interest by comparison of low yield nuclear and high explosive craters in various geologies. Figure A.1 depicts 1 Megaton crater profiles for two geology types as specified in 1972 **EM-1**. ...

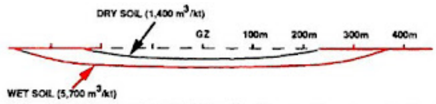


Figure A.1. 1 Mt Contact Burst Crater Profiles for Two Generic Geologies as Specified by DNA EM-1 (1972)

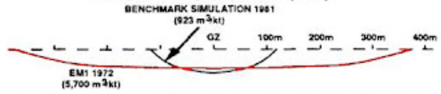


Figure A.2. Comparison of 1 Mt Contact Profiles for Two Generic Geologies as Specified by EM-1 (1972) and Predicted by DNA Benchmark Numerical Simulation (1981)

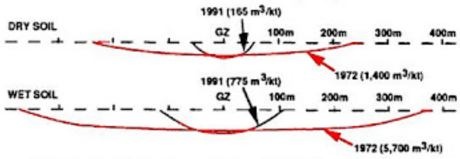


Figure A.5. Comparison of Current DNA Specification for 1 Mt Crater Profiles with 1972 Specifications

The numerical simulations indicated that strategic yield sources would produce craters one-third to one-fifth the scaled size produced in these events due to the relative inefficiency of the x-ray coupling process relative to hydrodynamic coupling. ...

Today, DNA relies on numerical cratering and ground shock simulations as key integral parts of its experimental program. They are the basis for cratering specifications for near-surface bursts in **EM-1, 1991**. Figure A.5 compares 1991 EM-I craters on two geology types to the profiles perceived in 1972. This dramatic shift in perception is based on the compelling evidence obtained in the highly successful field program discussed in this article. The current DNA reliance on numerical simulations is a result of the recognition that they provided the motivation for this program, enabled the success of the field activities, and today provide the means to apply this test experience to specific strategic weapon and geology combinations of interest. ...

In the earlier blog post (recently updated) on Glasstone and Dolan, I pointed out that, along with most effects, the crater predictions given by Glasstone and Dolan are massive exaggerations for high yields. There is a transition from cube-root explosive crater dimensions scaling at yields up to a few kilotons, to fourth-root gravity scaling in the megaton range. The cube-root scaling law occurs because the energy needed to heat, shock and explosively disrupt air or soil is directly proportional to the mass of that air or soil. Thus, the volume of ambient air or soil subjected to a particular shock overpressure scales in directly proportion to the energy of the explosion; which means that the radius of that volume scales in proportion to the cube-root of the explosion energy.

For high yield surface bursts, however, there is another vitally important use of energy in order to excavate a big crater: the energy needed to do work against gravity in order to raise the mass of dirt from the hole and dump it outside to form the 'lip' and 'ejecta' region around the crater (afterwind lofted fallout dust is merely ~1% of the crater mass). This energy is simply $E = mgh$ where m is the cratered mass raised average height h against gravitational acceleration g. Taking this into account means that for high yields h and particularly m both become very large, so that the gravitational work energy needed to form a massive crater is immense and can then exceed that of the explosive break-up of the soil. (For low yields, the gravitational work energy is trivial compared to that used to break up the soil explosively, because of the smaller mass and smaller crater depth.) If the crater diameter to depth ratio is constant, then the cratered mass m is proportional to the cube of the depth h, or $m = bh^3$ where b is a constant, so $E = mgh = bh^3gh = bh^4g$. Rearranging, $h \sim E^{1/4}$ for high yields. There are other factors involved of course, because the amount of energy used for cratering is essentially the downward-directed case-shock energy of the bomb debris (the air blast doesn't have enough density and thus enough momentum to dig out the crater, it just causes some compression). This is a limited fraction of the explosion energy, so the energy utilization in explosively heating, compressing and breaking up the crater material limits the energy available for ejecting it against gravity. This energy balance will usually be accompanied by some change in the ratio of crater diameter to depth, so the craters will not always exactly behave the fourth-power scaling law in the megaton range. **Nevertheless, there is a massive exaggeration of high-yield crater sizes in the *Effects of Nuclear Weapons* 1977 and related documents.**

The earliest mainstream American statement made that crater dimensions theoretically scale as $W^{1/4}$ for the regime in which gravity is important is by Dr Milo D. Nordyke of the Lawrence Radiation Laboratory in *Cratering Experience with Chemical and Nuclear Explosives* (published in *Proceedings of the Third Plowshare Symposium, Engineering with Nuclear Explosives, April 21, 22, 23, 1964*, U. S. Atomic Energy Commission report TID-7695, TID-4500 (UC-35), pages 51-53. Nordyke states there on page 52: "... the analysis that leads to $W^{1/3}$ ignores the action of several factors such as gravity and the strength or internal frictional forces of the medium. ... one can show that their effect would be to lower the exponent and lead toward $W^{1/4}$ scaling (reference: L. I. Sedov, *Similarity and Dimensional Methods in Mechanics,* Gostekhizdat Press, Moscow, 1954 and Academic Press, New York, 1959, page 251)."

However, Nordyke did not identify the $W^{1/4}$ as applying to the gravity regime for large megaton range explosions that excavating large masses of ejecta over large vertical distances against gravity, and the $W^{1/3}$ law holds for relatively small craters in the sub-kiloton range. Instead, he argued for an interim value of the exponent between the values of 1/3 and 1/4, of about $W^{1/3.4} \sim W^{0.3}$ from empirical data for Nevada desert alluvium. This fudge factor leads to inaccurate extrapolations from the Nevada test data.

Further reading:

> **'Data on the coral craters are incorporated into empirical formulas used to predict the size and shape of nuclear craters. These formulas, we now believe, greatly overestimate surface burst effectiveness in typical continental geologies ... coral is saturated, highly porous, and permeable ... When the coral is dry, it transmits shocks poorly. The crushing and collapse of its pores attenuate the shock rapidly with distance ... Pores filled with water transmit the shock better than air-filled pores, so the shock travels with less attenuation and can damage large volumes of coral far from the source.'**

– L.G. Margolin, et al., *Computer Simulation of Nuclear Weapons Effects,* Lawrence Livermore National Laboratory, UCRL-98438 Preprint, 25 March 1988, p. 5.

> **'It is shown that the primary cause of cratering for such an explosion is not "airslap," as previously suggested, but rather the direct action of the energetic bomb vapors. High-yield surface bursts are therefore less effective in cratering by that portion of the energy that escapes as [X-ray] radiation in the earliest phases of the explosion.'**

- H. L. Brode and R. L. Bjork, *Cratering from a Megaton Surface Burst,* RAND Corp., RM-2600, 1960.

D. E. Burton, et al., *Blast induced subsidence in the craters of nuclear tests over coral,* Lawrence Livermore National Lab., UCRL-91639, 1985:

> **"The craters from high-yield nuclear tests at the Pacific Proving Grounds are very broad and shallow in comparison with the bowl-shaped craters formed in continental rock at the Nevada Test Site and elsewhere. Attempts to account for the differences quantitatively have been generally unsatisfactory. We have for the first time successfully modeled the Koa Event, a representative coral-atoll test. On the basis of plausible assumptions about the geology and about the constitutive relations for coral, we have shown that the size and shape of the Koa crater can be accounted for by subsidence and liquefaction phenomena. If future studies confirm these assumptions, it will mean that some scaling formulas based on data from the Pacific will have to be revised to avoid overestimating weapons effects in continental geology."**

Another source of information on the revision of crater dimensions is **pages 136-139 of the 1993 book by Bruce G. Blair, *The Logic of Accidental Nuclear War,* published by the Brookings Institution, online here**:

> "Recently the U.S. Department of Defense reviewed the pertinent historical evidence gathered during nuclear tests and developed new models of the vulnerability of underground structures to nuclear explosions. These calculations differed substantially from those derived from earlier models. For example, the dimensions of a crater produced by a nuclear explosion were estimated to be considerably smaller than previously thought. To give a specific comparison, the radius of a crater produced by a one-megaton nuclear explosion on the surface of wet soil would be 651 feet according to the old formula, whereas the new formula estimated the radius to be 394 feet. ... Comparable differentials typically hold across the spectrum of weapon yields and soil varieties. ...
>
> "... Under the new formula the pertinent calculations for this location's geological composition (dry soft rock, according to U.S. analysts) indicate a crater radius of only 180 feet for a one-megaton weapon, or 262 feet for a nine-megaton weapon."

Notice that an increase in crater radius from 180 to 262 feet for a yield increase from 1 to 9 megatons implies a crater scaling power law of $W^{0.171}$, i.e. $180(9\text{ Mt} / 1\text{ Mt})^{0.171} = 262$ feet.

Holsapple's online crater scaling program

Keith A. Holsapple has a very nice and useful online crater scaling program at **http://keith.aa.washington.edu/craterdata/scaling/index.htm** which allows you to predict crater sizes for comet and asteroid impacts, chemical explosives, and also any yield and burst conditions from two types of nuclear weapon design:

(1) "high weight/energy ratio" inefficient low yield devices typical of early kiloton Nevada tests with a mass to yield ratio of 10 kg/kt, and

(2) "low weight/energy ratio" efficient high yield modern thermonuclear weapons with a mass to yield ratio of 0.42 kg/kt).

He also includes TNT, which of course has a massive weight to yield ratio of 1,000,000 kg/kt by definition. The dense explosion debris embeds itself deeply into the ground, delivering energy deeply into the ground far more efficiently than X-rays which just ablate a surface layer and cause a rapidly attenuated ground shock by the recoil from ablation. Efficient (high energy/weight ratio) nuclear weapons release most of their energy initially as X-rays not the kinetic energy of the dense debris shock wave, so they do not couple much energy deeply into the ground to cause a crater. As a result, high yield modern nuclear weapons use a much smaller proportion of their energy for cratering than inefficient low yield weapons or TNT chemical explosive.

Holsapple gives a sketchy account of the theory in his paper *Theory and equations for "Craters from Impacts and Explosions"* online here: **http://keith.aa.washington.edu/craterdata/scaling/theory.pdf** which for nuclear craters cites:

K. A. Holsapple and S. Peyton, *The Scaling of Nuclear Weapons Effects for Near Surface Bursts,* Defense Nuclear Agency report DNA 6543F (1987), and

R. M. Schmidt, K. R. Housen and K. A. Holsapple, *Gravity Effects in Cratering,* Defense Nuclear Agency report DNA-TR-86-182 (1988).

The approach Holsapple used is the scaling of experimental data through the use of dimensional analysis where the data is allowed to determine the scaling law at high yields, rather than fitting the data to determine coupling constants in a purely physical, mechanistic scaling model based on energy utilization. His equations 6 and 7 show that at low energy yields, the crater size is a stronger function of yield than at higher yields. The low yield limit is called the "strength regime" and crater sizes scale approximately as the cube-root of yield in this regime; at higher yields the scaling is in the "gravity regime" which is a weaker function of yield, closer to the fourth-root. Holsapple in equation 7 gives a "general form with those limits and that interpolates between these two regimes".

One problem is that he gives no derivation of the interpolative formula 7, and another problem is that the limits for the strength regime and gravity regime are not fixed theoretically as cube root and fourth root scaling in his formula, but are defined by experimental data. This is similar to modelling thermal radiation through the atmosphere by simply modifying the inverse-square law to fit the data, e.g. taking the thermal radiation to fall as say $1/R^{2.5}$, instead of adding an exponential term to allow for absorption and scattering by the atmosphere in addition to the inverse square law.

The problem is that we know from physical energy utilization principles that the laws of nature are due to fixed mechanisms and should be fixed theoretically. Variations in the experimental data should be used not to vary the scaling laws provided by the physical mechanism, but instead to determine the physical constants. At low yields, a unit amount of cratering energy excavates a unit mass of soil or rock. If the soil or rock has fixed density, the crater volume at low yields is then directly proportional to the energy yield. By geometry, the radius of a hemisphere is proportional to the cube-root of its volume. If the crater radius-to-depth ratio is a constant, this cube-root law applies to other shapes, too.

Hence, at low yields the cratering theory needs to be tied to the cube-root. At high yields, the influence of gravity is that most of the available cratering energy must be used up in shifting soil or rock out of the massive crater. The energy needed to lift crater mass M up to vertical distance to the lip D against the force of gravity F = Mg is simply E = FD = MgD. This is just a physical fact of nature. Since for a constant crater radius-to-depth ratio, the mass M is proportional to D^3, we get $E \sim D^3 D \sim D^4$, hence at high yields the energy used to overcome gravity predominates. The full equation for the utilization of energy is:

$E = AD^3 + BD^4$,

where the first term on the right hand side (containing D^3) is the energy needed to hydrodynamically excavate the mass of the crater (this energy is directly proportional to the mass of the crater or to the cube of the crater dimensions), and the second term on the right hand side (containing D^4) is the energy needed to overcome gravity and dump the excavated soil on the surrounding ground to form the crater lip and ejecta zone. So this is the simplest way to model craters: just use the experimental data to determine the values of constants A and B. Instead of this energy utilization and physical mechanism based approach, Holsapple allows the experimental data to vary the values of the powers that in fact should not be allowed to vary unless the radius-to-depth ratio of the crater varies.

The crater scaling formula that Holsapple gives allows the excavated volume of the crater to vary linearly with bomb yield at low yields ("strength regime"), correctly giving $W^{1/3}$ scaling for linear dimensions, but at high yields it gives a scaling law of $W^{\{mu\}/2}$ where {mu} should theoretically be equal to ½ from the physical laws of nature as they are known for constant radius-to-depth ratio craters to give the $W^{1/4}$ scaling law at high yields (gravity regime). By letting {mu} vary according to the explosive and impact cratering data in his database, however, Holsapple gets differing values for {mu}, from 0.41 for dry soil to 0.55 for wet soils, soft rock, hard soil and hard rock. For {mu} = 0.55, the scaling law for the high yield (gravity regime) asymptote will be $W^{0.55/2} = W^{0.275}$ instead of the physically defensible $W^{1/4}$ which is needed for energy conservation! Moreover, the data in Holsapple's database are mainly data for the strength regime. He doesn't have strong evidence of a departure from the natural $W^{1/4}$ scaling law. So we disagree with the scaling procedure unless {mu} is taken as ½ and the experimental data is just used to constrain the values of the *other* variables in the scaling procedure. The dimensional analysis formula used to interpolate in the all-important transition zone (which spans the most important yield range for nuclear weapons) from strength to gravity scaling, is also suspect, and **we would prefer a simple physical prediction system based on energy utilization between the hydrodynamic break up of the ground and the work against gravity in ejecting debris to form the lip and ejecta zone (as outlined in an earlier post, linked here).**

However, **online calculations using Holsapple's computer program does provide some interesting updates to our information**. Holsapple's computer calculation for explosion cratering works by using an equation based on dimensional analysis and data to predict crater excavation volumes for four different kinds of soil: dry soil, wet soil, hard soil/soft rock, and hard rock. The crater excavation volume is constrained to be directly proportional to bomb yield for very low, sub-kiloton yields (the "strength regime", corresponding to cube-root scaling for linear dimensions such as depth and radius) but less than directly proportion to yield for very high yields such as in the megaton range (the "gravity regime", where we argue that the energy to excavate against gravity is E = mgh ~ [volume]*[volume]$^{1/3}$ ~ [volume]$^{4/3}$ so that [volume] ~ $E^{3/4}$, which makes linear dimensions scale as $E^{1/4}$).

For example, for TNT (not nuclear explosive) surface burst (with the charge half-buried in the ground, so that the centre of the explosion at at ground level), Holsapple's computer program shows that at TNT yields equal to or less than 100 kg, the excavated volume in dry soil is $39{,}570W_{kt}$ cubic metres. But if you increase the yield to 1 kt of TNT explosive, you don't get a crater of 39,570 cubic metres, but only 16,600, because gravity effects are already starting to kick in. This figure of course is bigger than for a nuclear explosion.

Holsapple's model shows that the crater excavation volume for a low weight-to-energy ratio nuclear weapon ($0.4186W_{kt}$ kg bomb mass) is

actually 10 times less than for a high weight-to-energy ratio nuclear weapon ($10W_{kt}$ kg bomb mass) and is 25 times smaller than the crater volume produced by 1 kt of actual TNT ($1{,}000{,}000W_{kt}$ kg bomb mass).

For example, the crater volume for a 1 kt low mass-to-energy ratio nuclear warhead surface burst on dry soil is 664 m^3, compared to 6,640 for high mass-to-energy ratio nuclear warhead, and to 16,600 for actual TNT.

The heavier the bomb mass, the more efficient is the cratering effect, because more energy is carried downwards on dense, high-momentum bomb debris that embeds itself into the ground and delivers energy efficiently, unlike the X-ray surface ablation and the blast wave reflection from the ground, which produce a ground shock but no cratering. For the low mass-to-energy ratio nuclear warhead (which produces the significant smallest cratering action) on dry soil, Holsapple's program gives the following crater excavation volumes as a function of total yield:

1 kt: 664 m^3
10 kt: 4,680 m^3
100 kt: 32,200 m^3
1 Mt: 220,000 m^3
10 Mt: 1,490,000 m^3

Once the volume is calculated by the semi-empirical dimensional scaling equation, the program uses that volume to find the other crater parameters. Holsapple states that the density of dry soil is 1.7 grams/cm^3, but calculates the mass of crater ejecta as 80% of that (1.36 grams/cm^3) because not all of the crater volume is formed by ejecting material: there is also a soil compression effect below the bomb, and this accounts for the other 20% of the crater mass (which is compressed downward instead of being ejected out of the crater). This 80% figure is applied to all types of soil.

The density of dry soil is 1.70 grams/cm^3, but as stated only 80% of the crater volume is ejected so the mass of ejecta per unit volume is 0.8*1.70 = 1.36 grams/cm^3. For wet soil, hard rock and soft rock, the density is 2.10 grams/cm^3, and the ejected mass to volume ratio is 0.8*2.10 = 1.68 grams/cm^3. For hard rock, the mass density is 3.20 grams/cm^3, and the ejected mass to volume ratio is 0.8*3.20 = 2.56 grams/cm^3.

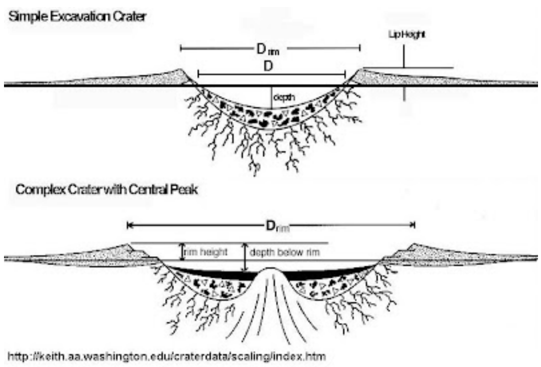
In all cases of weapon type and soil type, Holsapple's model uses the following relationships to calculate crater dimensions from the crater excavation volume *V:*

Apparent crater radius, $R_a = 1.10V^{1/3}$
Rim radius, $R_{rim} = 1.30R_a$
Apparent depth, $D_a = 0.60V^{1/3}$
Average lip height, $H_{lip} = 0.17D_a$
Crater formation time, $T_{formation} = 0.8V^{1/6}/g^{1/2}$ where acceleration due to gravity $g = 9.81$ ms^{-2} for Earth. (Most of the crater volume is ejected within a couple of seconds for any nuclear explosion, since the time taken is a weak function of yield.)

Information on the distribution of crater ejecta velocities is also provided. For a low mass-to-energy ratio nuclear weapon surface burst on dry soil, 50% of the ejecta exceeds 13.5 m/s for 1 kt or 30.1 m/s for 1 Mt.

For extremely high yields, there is a transition to "complex" craters like lunar craters, having a wide shallow basin and a central peak. Complex craters have their shape because they are too large for all the excavated material to be dumped at the lip; the fallback of ejecta in the centre of the crater is then so substantial it causes a central peak in the middle of the crater.

On the Earth, crater exceeding a rim diameter exceeding 1.77 km for dry soil would start to transition into "complex" craters. Obviously, there is a difference in this between Earth and Moon because there are no significant afterwinds in an explosion caused by an impact event on the Moon: there is a lack of atmosphere. But on the Earth, a large explosion near surface level causes a toroidal fireball to form due to air drag on the sphere, and you then get debris being sucked into the toroidal circulation via a mushroom "stem" above ground zero. On the Moon, which has only one-sixth of the surface gravity of the Earth, the transition from simple to complex cratering occurs at a rim diameter of 8.5 km. These complex craters are more relevant to impact cratering **like the K-T event 65.5 million years ago**, than to the relatively trivial energy releases of stockpiled nuclear explosives.



Peaceful cratering: the U.S. Atomic Energy Commission's *Project PLOWSHARE*

After the fallout from the *CASTLE-BRAVO* 14.8 megaton Bikini Atoll hydrogen bomb produced media hysteria over the effects of thermonuclear weapons, President Eisenhower responded by ordering the development and **testing at Bikini Atoll of *REDWING-NAVAJO* of the 95 % clean 4.5 megaton hydrogen bomb.** Aside from averting collateral damage from fallout in tactical nuclear war to defend Western Europe from invasion by the massive conventional Soviet block armies, this kind of cleaner weapon was also intended for peaceful civil engineering use as a cratering explosive. The first peaceful underground *PLOWSHARE* test in 1957 was such a success that it convinced America to move above ground nuclear testing underground to avoid fallout radiation hazards.

John Lindsay-Poland's book *Emperors in the jungle: the hidden history of the U.S. in Panama* (2003) gives in Chapter 3, "The Nuclear Canal", a critical but detailed example of another *PLOWSHARE* cratering project in the story of this peaceful use of the clean hydrogen bomb.

This plan was to set off 275 relatively clean hydrogen bombs to cheaply (at an estimated cost of roughly one billion dollars, which was cheap compared to the cost of using conventional explosives) create a new sea-level (without any locks) Panama canal in the Darien region, near the border with Colombia. The existing Panama canal has locks and isn't at sea-level, so it takes a long time for ships to pass through it, making it slow and expensive for ships to use to cross from the Atlantic to the Pacific Ocean.

View Larger Map

Above: in order to proof-test nuclear cratering for a new Panama canal, the 30 % fission, 104 kt total yield *PLOWSHARE-SEDAN* nuclear test was detonated at 635 feet depth (to optimize cratering efficiency and minimize fallout by trapping the radioactive case shock debris in the crater ejecta) in the dry soil of the Nevada Test Site on July 6, 1962. Although *SEDAN* was a success, the soil around some of the proposed Panama canal routes was not dry soil but saturated clay, which can create a wider, shallower shaped crater than dry soil. Hence, to get the depth required, higher yields than *SEDAN* would have been required for a new Panama canal. This would have increased the distant blast wave refraction effects (downwind of the high altitude winds), the ground shock (earthquake-type) effect, and fallout (although it is easier to reduce fission yield at very large total yields than very small ones, for instance the 50 Mt Soviet test was only 2-3 % fission). Both the distant blast and fallout effects could have been averted by postponing detonation until the winds were blowing out to sea, but ground shock effects from the large number of simultaneous high yield underground nuclear detonations required might have damaged the nearby existing Panama Canal, depending on the exact route taken, the distance, and the distribution of bomb yields used. The project was finally cancelled in 1971 due to **lying propaganda about alleged low-level radiation effects in the popular media.**

OTHER SOURCES OF INFORMATION ON CRATERING:

Patteson, A. W, *Physical Characteristics of Craters from Near-Surface Nuclear Detonations*, report AD0360630, 1960.

***Proceedings of the Third Plowshare Symposium Engineering with Nuclear Explosives Held in Davis California on April 21-23, 1964*, University of California report ADA396463, 1964.**